

SAND REPORT

SAND2006-5100
Unlimited Release
Printed August 2006

Laboratory Measurement Verification of Laser Hazard Analysis for MILES Weapon Simulators Used In Force on Force Exercises

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Abstract

Due to the change in the batteries used with the Small Arm Laser Transmitters (SALT) from 3-volts dc to 3.6-volts dc and changes to SNL MILES operating conditions, the associated laser hazards of these units required re-evaluation to ensure that the hazard classification of the laser emitters had not changed as well. The output laser emissions of the SNL MILES, weapon simulators and empire guns, used in Force-On-Force (FOF) training exercises, was measured in accordance to the ANSI Standard Z136.4-2005, Recommended Practice for Laser Safety Measurements for Hazard Evaluation. The laser hazard class was evaluated in accordance with the ANSI Standard Z136.1-2000, Safe Use of Lasers, using “worst” case conditions associated with these MILES units. Laser safety assessment was conducted in accordance with the ANSI Standard Z136.6-2005, Safe Use of Lasers Outdoors. The laser hazard evaluation of these MILES laser emitters was compared to and supersedes SAND Report SAND2002-0246, Laser Safety Evaluation of the MILES and Mini MILES Laser Emitting Components, which used “actual” operating conditions of the laser emitters at the time of its issuance.

Summary

1. All 53 of the Schwartz Electro-Optics SALT units tested were verified as presenting no greater than a Class 1 Laser Hazard (“eye safe”) for unaided viewing even with the use of enhanced voltage batteries.
2. All SALT (LMG) posed no greater than Class 1 Laser Hazard (“eye safe”) for aided (7x50mm) viewing even with the use of enhanced voltage batteries.
3. All five of the SEO LTE Controller laser emitters tested were verified as presenting no greater than a Class 1 Laser Hazard (“eye safe”) for both aided as well as unaided viewing – unchanged from previous evaluation.
4. Unless there is an increase the in Lithium battery voltage above the 3.6 volt (nominal) for the SEO SALT or there is a change in the operation protocol which might increase the laser emitter output no further verification of Class 1 Laser Operation is needed or recommended.
5. Prior to SEO LTE Controller use verify that the near “limiting” aperture (washer) is still in place cemented to the inside of the output IR window, by opening the housing and looking at the inside of the IR window.

Acknowledgements

The author would like to acknowledge and thank Jonathan Snell (Dept. 10327), SNL Laser Safety Officer, Alice M. Sobczak (Dept. 05719) Deputy Laser Safety Officer and Gary Moses (04211) Protective Force for their technical review of this report.

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I. Introduction

This laser hazard analysis and laser safety evaluation of Schwartz Electro-Optics MILES laser emitters is an updated supplemental to a previously released SAND Report⁴. In the case where SEO SALT units use the enhanced voltage Lithium batteries this evaluation supersedes the previously released report. The MILES laser emitter descriptions, background discussions and general operating conditions are detailed in that previous SAND report⁴.

The previous hazard analysis was based on the actual “as is” laser performance, as measured in the lab and the field, of the MILES laser emitter components, with no adjustments to output levels. The SEO SALT units at the time employed a nominal 3-volt rechargeable Lithium battery. The results of the previous hazard analysis indicated that the “as is” laser hazard class of these components were Class 1 for all the SEO SALT weapon simulators, Class 3A (physically modified to Class 1) for aided viewing of the empire guns in regards to all of the appropriate standards^{1,5,&10}, and the laser performance guide⁶. The use of these laser emitters in outdoor Force-On-Force (**FOF**) exercises did not pose an ocular laser hazard to the participants and had met the conditions of the governing outdoor laser weapon simulator standards^{3,7,8,&9}.

The previous analysis⁴ compared the individual component output to the individually determined Class 1 Accessible Emission Limit (**AEL**) for each component based on the individual component’s operating parameters. As reported previously, the individual Class 1 AEL, per pulse, was a function of the individual Maximum Permissible Exposure (**MPE**). These were presented in *SAND2002-0246 (Table 5)*. The individual Class 1 AEL is also a function of the number of pulses (**n**) presented in the lasing event.

$$Class\ 1\ AEL_{per\ pulse} = (493 \times 10^{-9} J) \cdot n^{-0.25}$$

As stated in the previous analysis, because of the unique pulse coding used to identify each MILES weapon simulator unit’s user and the weapon type, the pulse positions were not uniformly spaced yielding some uncertainty in the determination of the Pulse Repetition Frequency and hence the number of pulses in the exposure. As a result of this uncertainty, the number of pulses in the exposure for each individual unit was presented with a different AEL for its hazard class determination. These were presented in various tables [*SAND2002-0246 (Tables 7, 8, 9, & 10)*].

Change in the SALT Power Source

The SALT (Small Arms Laser Transmitter) units had previously been powered with a SEO (model 31821108-9) 3-volt rechargeable Lithium battery. Due to the limited operation time of the SALT units (as a result of limited electrical charge of these rechargeable batteries) they were replaced with a **3.6-volt** consumable Lithium battery.

As a consequence of the increased voltage of the power source, the power/energy level of the output laser pulses was likewise expected to increase. This possible increase in the SALT unit's output level requires that these units be reassessed to verify that they still presented a Class 1 Laser Hazard as required by SNL for FOF exercises.

New XENO Energy model XL-060F 3.6-volt lithium batteries were uniquely numbered and the outputs were measured with a Fluke model 87III multimeter, serial number 84910220, and presented in the table below. The Fluke multimeter dc voltage calibration was verified using The Eppley Laboratory, Inc. Standard Cell – Voltage Reference (10.19 vdc), SN F2264 the measurement error was less than 0.1%.

Table 1

Lithium Battery Voltage

#	Nominal (volts)	Measured (volts)
1	3.6	3.659
2	3.6	3.674

Change in SALT Operation for the M16 Rifle

The previous assessed operation of the SEO SALT laser emitters addressed the automatic as well as the semi-automatic mode of operation for the M16 Rifle. The M16 Rifle mode of operation for FOF exercises has now been **limited to the semi-automatic mode only**.

This analysis will compare the laser component emission measurements, according to measurement standards^{1&2}, to the appropriate Accessible Emission Limits for the appropriate mode of operation.

II. Parameters

A. Laser Parameters

Table 2

Laser Parameters¹⁴

Wavelength (λ):	904 nm
Pulse duration (t_p):	80 to 120 ns
Pulse Rate (PRF):	480 Hz

B. Operation Parameters

Exposure Time (T_{exposure}) is defined as the time for the completion of the output pulse train, not to exceed the 10 seconds [*ANSI Std. Z136.1-2000 (8.2.2) & (Table 4a)*].

Table 3

Operation Parameters

SALT	Model	Mode	Exposure* (seconds)
Rifle/M16	AM5000A	Semi	~0.5
Rifle/M302	AM5000B	Semi	-
Light Machine Gun	AM5010A	Auto	2.75
Control Gun	LTE2055	-	10
Control Gun	LTE2056	-	10

*SAND Report SAND2002-0246, page 19.

III. Hazard Analysis

A. Maximum Permissible Exposure

The determination of the appropriate MPE for repetitive-pulse lasers is given in *ANSI Std. Z136.1-2000 (8.2.3)* as the **smallest** of the MPE values of the MPE forms presented in *ANSI Std. Z136.1-2000 (Table 5a)* determined by the evaluation of each of the **ANSI Rules 1, 2 & 3**.

The MPE for each of the ANSI rules was evaluated and presented in Table 4 of the previous SAND report⁴. The appropriate MPE was derived from ANSI Rule 3.

$$MPE_{rule3} = \left(1.28 \times 10^{-6} \frac{J}{cm^2}\right) \cdot n^{-0.25} \quad [SAND2002-0246 (Table 4)]$$

Where (n) is the number of laser pulses in the exposure, for exposures less than or equal to 10 seconds [*ANSI Std. Z136.1-2000 (Table 4a)*].

Rifle/M16

For the **worst case** operation of the SEO Model AM5000A M-16 Rifle simulator (currently set for and limited to the **semi-automatic** mode of operation) the maximum PRF is given as 480 Hz¹¹ and the SALT emission time was previously measured to be about 0.5 seconds (*SAND2002-0246, page 19*).

The worst case number of laser pulses in this lasing event is:

$$\begin{aligned} n_{worst\ case} &= PRF_{max} \cdot T_{semi-auto} \\ &= (480 \text{ sec}^{-1}) \cdot (\sim 0.5 \text{ sec}) \\ n_{worst\ case} &\approx 240 \text{ pulses} \end{aligned}$$

Worst case MPE for the M16 Rifle (semi-automatic) simulator is then:

$$\begin{aligned} MPE_{M16} &= \left(1.28 \times 10^{-6} \frac{J}{cm^2}\right) \cdot (240)^{-0.25} \\ &= \left(1.28 \times 10^{-6} \frac{J}{cm^2}\right) \cdot (0.254) \\ MPE_{M16} &\approx 325 \times 10^{-9} \frac{J}{cm^2} \end{aligned}$$

Light Machine Gun

For the **worst case** operation of the SEO Model AM5010A LMG simulator (currently set for the **automatic** mode of operation) the maximum PRF is 480 Hz and the SALT emission time was previously measured as 2.75 seconds (*SAND2002-0246, page 19*).

It was previously calculated that the maximum number of laser pulses (n_{\max}) present in the longest lasing event for the LMG simulator (with same magazine load as the M16 Rifle) was determined to be 1,320 pulses (*SAND2002-0246, page 20 & 26*).

Worst case MPE for the LMG (automatic) simulator is then:

$$\begin{aligned} MPE_{LMG} &= \left(1.28 \times 10^{-6} \text{ J/cm}^2\right) \cdot (1320)^{-0.25} \\ &= \left(1.28 \times 10^{-6} \text{ J/cm}^2\right) \cdot (0.166) \\ MPE_{LMG} &= 212 \times 10^{-9} \text{ J/cm}^2 \end{aligned}$$

M203 (40-mm Grenade)

The worst case operation of the SEO Model AM5000B M203 40-mm Rifle Mounted Grenade the maximum PRF is 480 Hz and the SALT emission time is less than one second.

$$\begin{aligned} MPE_{M203} &= \left(1.28 \times 10^{-6} \text{ J/cm}^2\right) \cdot (< 480)^{-0.25} \\ &\geq \left(1.28 \times 10^{-6} \text{ J/cm}^2\right) \cdot (0.214) \\ MPE_{M203} &\approx 273 \times 10^{-9} \text{ J/cm}^2 \end{aligned}$$

Empire (Control) Gun

The worst case operation of the SEO Model LTE 2055 Controller Gun the maximum PRF is 480 Hz and the laser emission time is as long as the trigger is engaged, where the standard exposure is limited to 10 seconds [*ANSI Std. Z136.1-2000 (Table 4a)*].

$$\begin{aligned} MPE_{LTE2055} &= \left(1.28 \times 10^{-6} \text{ J/cm}^2\right) \cdot (4800)^{-0.25} \\ &\geq \left(1.28 \times 10^{-6} \text{ J/cm}^2\right) \cdot (0.120) \\ MPE_{LTE2055} &= 154 \times 10^{-9} \text{ J/cm}^2 \end{aligned}$$

B. Class 1 Accessible Emission Limit

The Class 1 AEL is defined as the product of the MPE and the area of the limiting aperture [*ANSI Std. Z136.1-2000 (3.2.3.4.1 (2))*]. The appropriate AEL was evaluated in the previous SAND report⁴ and was presented in Table 5 of that report.

$$Class\ 1\ AEL_{per\ pulse} = (493 \times 10^{-9} J) \cdot n^{-0.25} \quad [SAND2002-0246\ (Table\ 5)]$$

Rifle/M16

The maximum number of laser pulses present in the SEO Model AM5000A (M-16 rifle simulator) has been shown to be 240 pulses.

Worst case AEL for the M16 rifle simulator (semi-automatic operation) is then:

$$\begin{aligned} Class\ 1\ AEL_{per\ pulse} &= (493 \times 10^{-9} J) \cdot (\sim 240)^{-0.25} \\ &\approx (493 \times 10^{-9} J) \cdot (0.254) \\ Class\ 1\ AEL_{per\ pulse} &\approx 125 \times 10^{-9} J \end{aligned}$$

Light Machine Gun

The maximum number of laser pulses present in the SEO Model AM5010A (LMG simulator) has been shown to be 1320 pulses.

$$\begin{aligned} Class\ 1\ AEL_{per\ pulse} &= (493 \times 10^{-9} J) \cdot (1320)^{-0.25} \\ &= (493 \times 10^{-9} J) \cdot (0.166) \\ Class\ 1\ AEL_{per\ pulse} &= 81.8 \times 10^{-9} J \end{aligned}$$

M203 40-mm Grenade

The maximum number of laser pulses present in the SEO Model AM5000B (M203 40-mm Grenade simulator) has been shown to be less than **480 pulses**.

$$\begin{aligned} \text{Class 1 } AEL_{\text{per pulse}} &= (493 \times 10^{-9} J) \cdot (< 480)^{-0.25} \\ &\geq (493 \times 10^{-9} J) \cdot (0.214) \\ \text{Class 1 } AEL_{\text{per pulse}} &\approx 105 \times 10^{-9} J \end{aligned}$$

Empire Guns

The maximum number of laser pulses present in the SEO Model LTE 2055 and LTE 2056 (Controller Guns) is limited to 4800 pulses.

$$\begin{aligned} \text{Class 1 } AEL_{\text{per pulse}} &= (493 \times 10^{-9} J) \cdot (4800)^{-0.25} \\ &= (493 \times 10^{-9} J) \cdot (0.120) \\ \text{Class 1 } AEL_{\text{per pulse}} &= 59.2 \times 10^{-9} J \end{aligned}$$

AEL Summary

Table 3

MPE/AEL Summary

Model	Emitters	Mode	MPE (nJ/cm ²)	AEL (nJ)
AM5000A	Rifle/M16	Semi	~325	~125
AM5000B	Rifle/M203	Semi	~273	~105
AM5010A	LMG	Auto	212	81.8
LTE2055	Controller	*	154	59.2
LTE2056	Controller	*	154	59.2

*Output as long as trigger is depressed.

IV. Measurements

A. Instruments

Previously the laser emitter output was measured using an Ophir PD-10 photodiode power head in conjunction with an Ophir NOVA meter⁴. The average pulse energy was determined by measuring the average radiant power and estimating the PRF of the pulse coded output. The average pulse energy was determined by dividing the average power by the estimated PRF.

The new Ophir NOVA II Power/Energy Monitor has the ability to measure the total energy during the lasing event and also count the number of laser pulses in the lasing event when the meter is set to the “exposure” mode of operation¹¹. The use of this technique eliminates the uncertainty in the number of pulses in the lasing event which has been shown to be critical in determining the appropriate AEL for laser classification [SAND2002-0246 (Table 5)].

Table 4
Measuring Instruments Used

Instrument Type	Manufacturer	Model	Serial Number	Calibration Date	Accuracy* %
Power/Energy Head	Ophir	PD10-SH	220952	28 Jun 06	± 5
Power/Energy Head	Ophir	PD10-PJ	217915	05 Apr 06	± 5
Display	Ophir	NOVA II	224655	15 Jun 06	± 0.5

* User Manual¹¹ and Data Sheet¹².

Effective Energy

The effective energy (Q_{eff}) used in laser hazard evaluation is the energy that is measured through the measurement aperture (D_M) [ANSI Std. Z136.4-2005 (4.1.3)]. The effective radiant energy was measured using the energy/power heads and monitor units listed in Table 4.

System Accuracy

The accuracy of the measurement system (energy head and the display meter) is the square root of sum of the squares of the individual component accuracies.

$$\begin{aligned}Accuracy_{sys} &= \pm \sqrt{(Head)^2 + (Meter)^2} \\Accuracy_{sys} &= \pm \sqrt{(\pm 0.05)^2 + (\pm 0.005)^2} = 0.0502 \\Accuracy_{sys} &= \pm 5.02\%\end{aligned}$$

The laser measure system accuracy is sufficient to meet the ($\pm 20\%$) system accuracy required by the ANSI Standard [*ANSI Std. Z136.1-2000 (9.3)*].

Measurement/Limiting Aperture

The Ophir® Model PD10-SH and the Model PD10-PJ energy/power heads have a measurement aperture of 10 mm (1 cm)¹². The measurement of irradiance or radiant exposure involve in hazard class determination are to be made with instruments that average over a circular area defined by the limiting aperture (D_f) [*ANSI Std. Z136.1-2000 (9.2.2.1)*]. The limiting aperture for a laser with a radiant output in the visible or near infrared part ($400 \text{ nm} \leq \lambda \leq 1400 \text{ nm}$) of the spectrum is given as 7 mm (0.7 cm) [*ANSI Std. Z136.1-2000 (Table 8)* & *ANSI Std. Z136.4-2005 (Table 1b)*]. An Optimization ceramic 7-mm aperture was centered and affixed to the energy/power head so that the measurement aperture for this evaluation is equaled to the “limiting aperture”(D_f).

$$D_M = D_f = 0.7 \text{ cm}$$

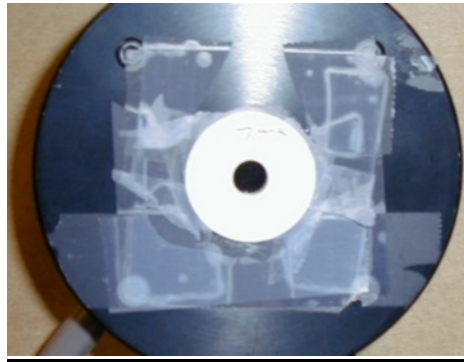


Figure 1

Ophir PD10-SH Photodiode Power Head with a 7-mm ceramic aperture centered on the active area.

The SALT units were mounted as shown in figure 2. The PD-10-PJ photodiode with the 7-mm aperture was placed 10 cm from the laser emitter as required [*ANSI Std. Z136.1-2000 (9.2.1.1)* and *ANSI Std. Z136.4-2005 (4.1.4.1) & Table 2a*] and centered on the output beam using an IR viewer (FJW Optical System Find-R-Scope).

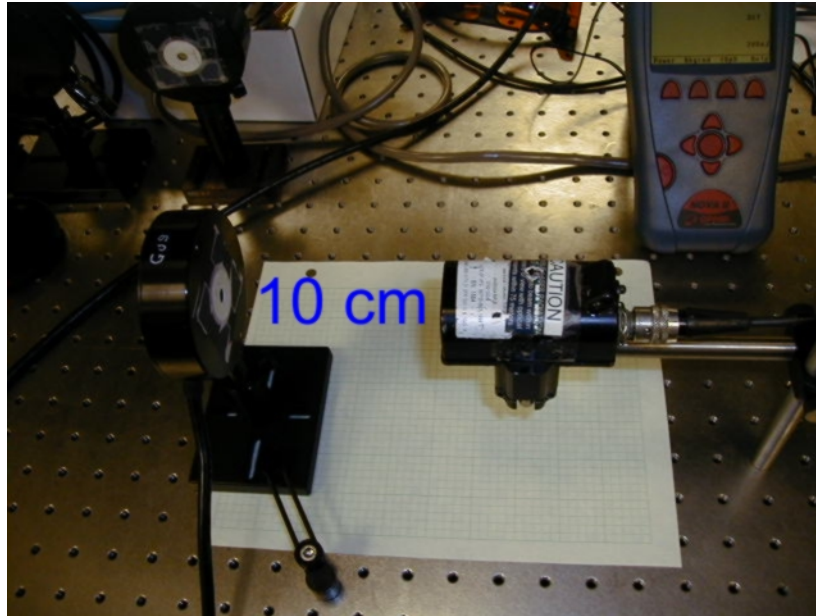


Figure 2

The SEO SALT unit output is measured by the Ophir Photodiode Power/Energy head with an attached 7-mm aperture which was placed 10 cm from the SALT

The Ophir NOVA II Power/Energy Monitor was set for:

Laser:	904 nm
Range:	200 nJ
Menu:	Exposure
Mode:	Manual (Start-Stop)

Average Pulse Energy

The NOVA II Power/Energy Monitor measures and displays the total energy received in a multiple pulse lasing event and counts the number of pulses in that lasing event. The average effective pulse energy (\bar{Q}_{eff}) is calculated by dividing the total effective energy received (Q_{tot}) in the exposure through the limiting aperture by the number of laser pulses (n) delivered in the exposure [Ophir NOVA II Power/Energy Monitor User Manual (4.5.5 (2))].

$$\bar{Q}_{eff} = \frac{Q_{tot}}{n}$$

The SALT units were set for “dry fire” and connected with a “dry fire” adapter pressure switch. The SALT unit/PD-10/NOVA II measurement system configuration was set up as shown in figure 2. The NOVA II Power/Energy Monitor “exposure” was manually started by pressing the “start” button and the “dry fire” pressure switch pressed once for semi-automatic operation (Rifle/M16 and Rifle/M203) and held for approximately 3 to 4 seconds for the LMG. The total energy and number of pulses were noted. The NOVA II Power/Energy Monitor was “reset” before initiating the next measurement. The average pulse energy was calculated by dividing the total measured effective energy by the number of laser pulses counted by the display. Three repetitions of each measurement were performed and the average of the three measurements was recorded as the “average pulse energy”. The results are presented in Tables 6 through 8.

Rifle/M16 & /M203

The number of laser pulses in each of the AM5000A Rifle/M16 simulator semi-automatic laser event was **counted** by the Ophir NOVA II to be **241** pulses compared to the **estimated** number of pulses: **240**. The number of laser pulses in each of the AM5000B Rifle/M203 40-mm Grenade simulator laser event was counted as 400 compare to ~480 pulses estimated.

LMG

The duration of the LMG lasing event using the dry fire pressure switch was between 3 and 4 seconds. The total of the energy-total pulse pair was evaluated to determine the average pulse energy for each run. The average of three such results is presented in Table 8.

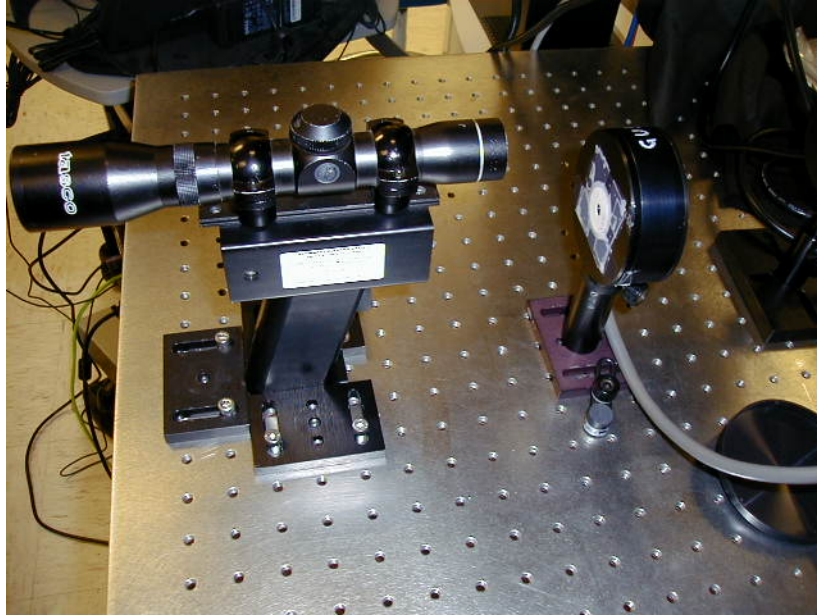


Figure 3

The SEO LTE 2055 Hand Held Controller output is measured by the Ophir PD10 Photodiode Power/Energy head with an attached 7-mm aperture which was placed 10 cm from the controller.

Controller

The SEO LTE 2055 Hand Held Controller was set up as shown in figure 3 and the LTE 2056 was set up as shown in figure 4. Both the LTE 2055 and LTE 2056 Controllers emits an output pulse train for as long as the pistol trigger is depressed, hence the standard 10-second exposure is the appropriate laser event time to use. The Ophir NOVA II was set for “power” measurement with a “1” second average. The Ophir PD10-PJ/NOVA II measured the average effective power through the 7-mm limiting aperture. The average effective pulse energy was determined by dividing the average power by the pulse repetition rate measured and displayed by the NOVA II Power/Energy Monitor.

$$\overline{Q_{eff}} = \frac{\overline{\Phi_{eff}}}{PRF} \quad [ANSI Std. Z136.4-2005 (5.3)]$$



Figure 4

The SEO LTE 2056 Hand Held Controller output is measured by the Ophir PD10 Photodiode Power/Energy head with an attached 7-mm aperture which was placed at the front of the controller.

V. Safety Evaluation

The results of the laser output measurements and subsequent Laser Hazard Classification for aided as well as unaided viewing of the various laser emitters are presented in the following tables (Table 6 to Table 15). **Blue** font indicates the number is a measured value whereas **magenta** font is used to depict the worst case Class 1 AEL value. The final calculated value is **green** font if the output is less than or equal to the Class 1 AEL, **red** font would indicate the value is greater than the Class 1 AEL – i.e. presenting a Class 3A or greater laser hazard. (Note all units tested below the Class 1 AEL.)

Table 6**Results for the SEO Model AM5000A Rifle/M16 – Unaided Viewing**

Unit Serial #	Average Total Energy (μ J)	Number Of Pulse n	Actual Average Pulse Energy (nJ)	Worst Case AEL/pulse semi-auto (nJ/)	Laser Hazard Class
1700	14.9	241	62.0	125	1
1701	16.9	241	70.2	125	1
1868	15.7	241	65.1	125	1
1869	16.5	241	68.5	125	1
1870	15.3	241	63.7	125	1
1871	15.0	241	62.1	125	1
1872	15.8	241	65.6	125	1
1873	15.8	241	65.7	125	1
1874	16.1	241	66.7	125	1
1875	16.3	241	67.5	125	1
1876	16.6	241	69.0	125	1
1877	15.3	241	65.1	125	1
1878	18.7	241	77.4	125	1
1879	15.4	241	64.0	125	1
1880	16.5	241	68.6	125	1
1881	17.8	241	74.0	125	1
1882	14.8	241	61.5	125	1
1883	16.7	241	69.2	125	1
1884	26.1	241	108	125	1
1885	14.8	241	61.5	125	1
1886	16.6	241	69.0	125	1
1887	15.5	241	64.5	125	1
1888	15.0	241	62.4	125	1
1889	14.9	241	62.0	125	1
1891	17.7	241	73.9	125	1
1892	16.4	241	68.1	125	1
1894	15.9	241	65.9	125	1
1896	15.6	241	64.9	125	1
1897	15.1	241	62.4	125	1
1898	17.4	241	72.3	125	1
1899	12.8	241	53.3	125	1
1904	16.5	241	68.5	125	1
1905	17.0	241	70.7	125	1
1906	15.7	241	65.0	125	1
1907	15.6	241	64.9	125	1

Table 7

**Results for the SEO Model AM5000B Rifle/M203 40-mm Grenade
– Unaided Viewing**

Unit Serial #	Total Energy measured* (μJ)	Number Of Pulses* (n)	Actual Average Pulse Energy measured (nJ)	Worst Case AEL/pulse semi-auto (nJ/)	Laser Hazard Class
1955	10.2	400	25.4	110	1
1956	10.8	400	27.0	110	1
1957	11.2	400	27.9	110	1
1958	10.6	401	26.3	110	1

*Measured with Ophir PD10-PJ/NOVA II (Energy Monitor)

Table 8

Results for the SEO Model AM5010A LMG – Unaided Viewing

Unit Serial #	Actual Average Pulse Energy Measured* (nJ)	Worst Case AEL/pulse semi-auto (nJ/)	Laser Hazard Class
3681	40.4	81.8	1
4016	42.4	81.8	1
4017	44.9	81.8	1
4019	35.9	81.8	1
4020	45.2	81.8	1
4022	40.4	81.8	1
4023	41.0	81.8	1
4029	35.9	81.8	1
4104	45.9	81.8	1
4107	43.0	81.8	1
4109	44.4	81.8	1
4110	42.0	81.8	1
4113	44.8	81.8	1
4875	48.5	81.8	1

*Measured with Ophir PD10-PJ/NOVA II (Energy Monitor)

Table 9

SEO LTE 2055 Hand Held Controller – Unaided Viewing

Unit Serial #	Average Power measured* (μ W)	PRF* (sec ⁻¹)	Actual Average Pulse Energy (nJ)	Worst Case AEL/pulse semi-auto (nJ/)	Laser Hazard Class
2007	14.3	473	30.2	59.2	1
2009	13.3	473	28.2	59.2	1
2010	11.4	473	24.0	59.2	1
2019	11.1	473	23.5	59.2	1

*Measured with Ophir PD10-SH/NOVA II (Power Monitor)

Table 10

SEO LTE 2056 Hand Held Controller – Unaided Viewing

Unit Serial #	Average Power measured* (μ W)	PRF* (sec ⁻¹)	Actual Average Pulse Energy (calculated) (nJ)	Worst Case AEL/pulse semi-auto (nJ/)	Laser Hazard Class
1003	15.8	471	33.6	59.2	1

*Measured with Ophir PD10-SH/NOVA II (Power Monitor)

All of the SEO laser emitters (tested) were verified, through physical measurements, to pose only a “Class 1” laser hazard (eye safe) for unaided viewing.

Aided Viewing

Aided viewing involves the use optical devices, such as, for example 7x50mm binoculars, used by personnel involved in the FOF exercise who might upon occasion view the laser emitter output using this viewing aid. This exposure is assumed to be 10 seconds or greater and under current standards **shall present only a Class 1 laser hazard** to the user.



Figure 5

Ophir PD10-SH Photodiode Power Head with a 10-mm ceramic aperture centered on the active area

The appropriate laser measurement used to evaluate aided viewing hazard is specified as the Power/Energy measured through a 50-mm aperture placed at 2 meters (200 cm) from the laser emitter with an assumed 90% optical transmission in the near IR [*ANSI Std. Z136.1-2000 (Table 9) & ANSI Std. Z136.4-2005 (Table 2a)*]. The power or energy that might be in the beam area outside this 50 mm aperture is disregarded.

The effective aperture of the Ophir PD10-SH is given as 1-centimeter¹¹; therefore, a focusing lens, with a 50-mm clear aperture, would have to be used in order to reduce the beam size to that under the 1 cm active aperture of the Ophir PD10-SH. The transmission through this lens would add some uncertainty to the measurement.

An alternate approach was made to take this measurement. The exit beam size for all the laser emitters were observed and found to be less than 1 centimeter in any dimension near the exit of the laser. Therefore the 7-mm limiting aperture (unaided viewing) was removed and a 10-mm ceramic aperture was centered over the Ophir PD10-PJ & the PD10-SH active areas (figure 5) to aid in alignment of the output laser spot on the Ophir PD10-SH. The exit laser spot was center on the active area of the Ophir Energy/Power Heads by the use of an IR view and verified that the laser spot was less than the active aperture, by not observing any IR illumination on the white ceramic aperture. The entire beam Power/Energy of the laser emitters were measured using the same set up as the unaided viewing but with a 10-mm aperture. This technique assumes all the power across the beam enters the collecting optic of the viewing aid.

The PD10-PJ was used to make energy total energy measurements with pulse counts for the SEO SALTs and the PD10-SH was used to make average power and PRF measurements of the SEO LTE Controllers.

Table 11**Results for the SEO Model AM5000A Rifle/M16- Aided Viewing**

Unit Serial #	Average Total Energy (μ J)	Number Of Pulse n	Actual Average Pulse Energy (calculated) (nJ)	Transmitted Pulse Energy (calculated) (nJ)	Worst Case AEL/pulse semi-auto (nJ/)	Laser Hazard Class
1700	20.6	241	85.7	77.1	125	1
1701	21.6	241	89.8	80.8	125	1
1868	21.3	241	88.5	79.6	125	1
1869	19.3	241	80.2	72.1	125	1
1870	20.3	241	84.2	75.8	125	1
1871	21.1	241	87.5	78.8	125	1
1872	20.0	241	82.8	74.5	125	1
1873	20.5	241	85.1	76.6	125	1
1874	19.5	241	80.9	72.8	125	1
1875	20.5	241	84.9	76.4	125	1
1876	21.0	241	87.3	78.6	125	1
1877	20.0	241	83.0	74.7	125	1
1878	21.3	241	88.3	79.5	125	1
1879	20.4	241	84.8	76.4	125	1
1880	20.7	241	85.7	77.2	125	1
1881	19.9	241	82.6	74.4	125	1
1882	19.5	241	81.0	72.9	125	1
1883	21.3	241	89.5	80.6	125	1
1884	27.4	241	114	102	125	1
1885	20.4	241	84.7	76.3	125	1
1886	21.4	241	88.8	79.9	125	1
1887	20.3	241	84.1	75.6	125	1
1888	21.0	241	87.0	78.3	125	1
1889	20.8	241	86.3	77.6	125	1
1891	20.8	241	86.3	77.6	125	1
1892	20.9	241	86.7	78.0	125	1
1894	20.4	241	84.1	76.1	125	1
1896	20.5	241	85.0	76.5	125	1
1897	20.7	241	85.7	77.2	125	1
1898	20.0	241	82.9	74.6	125	1
1899	18.1	241	75.1	67.6	125	1
1904	21.7	241	90.1	81.1	125	1
1905	20.1	241	83.5	75.2	125	1
1906	20.3	241	84.1	75.6	125	1
1907	21.3	241	88.5	79.6	125	1

Table 12

**Results for the SEO Model AM5000B Rifle/M203 40-mm Grenade
Aided Viewing**

Unit Serial #	Total Energy measured* (µJ)	Actual Number Of Pulses* (n)	Actual Average Pulse Energy (calculated) (nJ)	Transmitted Average Pulse Energy** (nJ)	Worst Case AEL/pulse semi-auto (nJ/)	Laser Hazard Class
1955	15.0	400	37.5	33.7	110	1
1956	16.0	400	40.1	36.1	110	1
1957	13.8	400	34.6	31.1	110	1
1958	13.0	401	32.4	29.2	110	1

*Measured with Ophir PD10-PJ/NOVA II (Energy Monitor)

**T = 0.9 [ANSI Std. Z136.1 (Table 9)] & [ANSI Std.Z136.4-2005 (Table 2a)]

Table 13

Results for the SEO Model AM5010A LMG – Aided Viewing

Unit Serial #	Actual Average Pulse Energy (measured*) (nJ)	Transmitted Average Pulse Energy** (calculated) (nJ)	Worst Case AEL/pulse semi-auto (nJ/)	Laser Hazard Class
3681	48.9	44.0	81.8	1
4016	54.8	49.3	81.8	1
4017	53.3	48.0	81.8	1
4019	44.2	39.8	81.8	1
4020	55.9	50.3	81.8	1
4022	54.8	49.3	81.8	1
4023	53.1	47.8	81.8	1
4029	42.2	44.3	81.8	1
4104	57.2	51.5	81.8	1
4107	52.2	47.0	81.8	1
4109	55.1	49.6	81.8	1
4110	54.0	48.6	81.8	1
4113	57.1	51.4	81.8	1
4875	56.5	50.8	81.8	1

*Measured with Ophir PD10-PJ/NOVA II (Energy Monitor)

**T = 0.9 [ANSI Std. Z136.1 (Table 9)] & [ANSI Std.Z136.4-2005 (Table 2a)]

Table 14

Aided Viewing of SEO LTE 2055 Hand Held Controller

Unit Serial #	Average Power measured* (μ W)	PRF* (sec ⁻¹)	Actual Average Pulse Energy (calculated) (nJ)	Average Transmitted Pulse Energy** (nJ)	Worst Case AEL/pulse semi-auto (nJ/)	Laser Hazard Class
2007	15.9	473	33.7	30.3	59.2	1
2009	14.6	473	30.8	27.7	59.2	1
2010	11.8	473	24.9	22.4	59.2	1
2019	11.4	473	24.1	21.7	59.2	1

*Measured with Ophir PD10-SH/NOVA II (Power Monitor)

**T = 0.9 [ANSI Std. Z136.1 (Table 9)] & [ANSI Std.Z136.4-2005 (Table 2a)]

Table 15

Aided Viewing of SEO LTE 2056 Hand Held Controller

Unit Serial #	Average Power measured* (μ W)	PRF* (sec ⁻¹)	Actual Average Pulse Energy (calculated) (nJ)	Average Transmitted Pulse Energy** (nJ)	Worst Case AEL/pulse semi-auto (nJ/)	Laser Hazard Class
1003	19.3	471	40.9	36.8	59.2	1

*Measured with Ophir PD10-SH/NOVA II (Power)

**T = 0.9 [ANSI Std. Z136.1 (Table 9)] & [ANSI Std.Z136.4-2005 (Table 2a)]

VI. Conclusions

1. All the SEO SALT laser emitters were verified as presenting no greater than a Class 1 Laser Hazard for unaided viewing and are considered “eye safe”.
2. All SALT units were verified as producing outputs less than the Class 1 Allowable Emission Limit for aided viewing and are considered “eye safe”.
3. All the SEO LTE Controller laser emitters were verified as presenting no greater than a Class 1 Laser Hazard (“eye safe”) for both aided as well as unaided viewing.
4. Unless there is an increase in Lithium battery voltage above the 3.6 volt (nominal) for the SEO SALT or there is a change in the operation protocol which might increase the laser emitter output no further verification of Class 1 Laser Operation is needed or recommended.
5. Prior to SEO LTE Controller use, verify that the near “limiting” aperture (washer) is still in place on the inside of the output IR window.

VII. References

1. ANSI Standard Z136.1-2000, for Safe Use of Lasers, Published by the Laser Institute of America.
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5. 21 CFR 1040, Laser Product Performance Standard.
6. CDRH, Compliance Guide for Laser Products, Food & Drug Administration.
7. FAA Order 7400.2E, Part 6, Chapter 29, Outdoor Laser Operations.
8. DOE Order 5480.16A, Firearms Safety.
9. DOE-STD-1091-96, Firearms Safety.
10. ACGIH, 2005 – Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices.
11. OPHIR NOVA II Laser Power/Energy Monitor User Manual, Ophir Optonics.
12. Pyroelectric and Photodiode Heads for Repetitive Pulses – Photodiode Heads PD10/PD10-PJ Data Sheet, OPHIR Laser Measurement Group, Ophir Optonics.
13. 27309216, Operation and Maintenance Manual – Model LTE 2055 Controller Gun, Schwartz Electro-Optics.
14. 31829203, Maintenance and Repair Manual – Rifle, Light Machine Gun and Heavy Machine Gun Laser Transmitter, Schwartz Electro-Optics.
15. 31829208, Hand Held System Controller Manual, Schwartz Electro-Optics.
16. 31829218, Enhanced MILES Decoder/Controller User's Manual, Schwartz Electro-Optics.

VIII. Abbreviations

AEL	Accessible Emission (Exposure) Limit
A_{lim}	Area of limiting aperture
ANSI	American National Standards Institute
C_p	Multiple-pulse correction factor
D_f	Diameter of limiting aperture
d_o	Output beam diameter
E	Irradiance, in W/cm^2
E_{eff}	Effective irradiance W/cm^2
E_o	Output Irradiance, in W/cm^2
EOHD	Extended Ocular Hazard Distance
FOF	Force on force
H	Radiant Exposure of the beam
Hz	Hertz, cycle per second, sec^{-1}
IR	Infrared
J	Joules, unit of energy
MILES	Multiple Integrated Laser Engagement System
Min[a,b]	Minimum of value of a and b
mJ	Millijoule, 10^{-3} Joules
MPE	Maximum Permissible Exposure
MPE_{cw}	Continuous Wave Maximum Permissible Exposure
MPE_{rule1}	Maximum Permissible Exposure based on ANSI Rule 1
MPE_{rule2}	Maximum Permissible Exposure based on ANSI Rule 2
MPE_{rule3}	Maximum Permissible Exposure based on ANSI Rule 3
$MPE_{thermal}$	Maximum Permissible Exposure based on the thermal limit
n	Number of pulses in the exposure
NIR	Near infrared
nm	Nanometer, 10^{-9} meters
NOHD	Nominal Ocular Hazard Distance
ns	Nanosecond, 10^{-9} seconds
NHZ	Nominal Hazard Zone
PRF	Pulse Repetition Frequency

Q	Radiant Energy, in Joules
Q_o	Output Radiant Energy, in Joules
$\overline{Q_o}$	Average Radiant Energy, in Joules
R	Range
SEO	Schwartz Electro-Optics
t	Exposure duration, pulse duration
T	Exposure duration, in seconds
W	Watts (unit of power)
\square	Beam divergence, in radians
\square	Radiant Power in watts
$\overline{\Phi}$	Average Radiant Power
\square	Wavelength
$\square m$	Micrometer, 10 ⁻⁶ meters

IX. Distribution

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